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**DETERMINING PATIENT-RELATED INFORMATION ON THE
POSITION AND ORIENTATION OF MR IMAGES BY THE
INDIVIDUALIZATION OF A BODY MODEL**

- 5 Method for determination of patient-related information regarding the position and orientation of slice image exposures in magnetic resonance tomographic examinations.

10 The invention concerns a method for determination of patient-related information regarding the position and orientation of magnetic resonance tomographic slice image exposures of a patient.

15 In an examination of a patient in a magnetic resonance tomography apparatus (MR apparatus), among other things information about in which position and orientation the respective exposures were made relative to the patient must be determined regarding the produced slice image exposures (exposures). Such patient-related information regarding the position and orientation of the slice image exposures are normally shown in a display or a printout of the exposures at the edges of the exposures and also enable a reconstruction of the spatial position of the exposures relative to the patient after the examination.

20 The acquisition plane in which a specific exposure is produced can, in principle, be defined within an arbitrarily-established reference coordinate system by the coordinates of directional vectors that span the appertaining acquisition plane. A uniform coordinate system, what is known as the "primary coordinate system" of the patient, is typically used as a reference coordinate system in radiological diagnostics. The axial directions of this primary coordinate system are thereby defined by the intersection lines of what are known as the "primary planes" (standing perpendicular to one another) of the body of the patient, whereby these primary planes are – as in anatomy – designated as transversal plane, sagittal plane and coronary plane. This is shown in Figure 1, whereby the transversal plane is

designated with the letter T, the sagittal plane is designated with the letter S and the coronary plane is designated with the letter C.

The precise orientation of a directional vector can be documented within this
5 primary coordinate system of the patient, for example via two angle specifications with regard to the coordinate system axes. However, for the operator such angle specifications can generally not be detected so quickly since the operator would then have to initially implement some conversions under consideration of the reference coordinate system in order to acquire the position of the slice image
10 exposure relative to the patient. Such angle specifications are thus not significant for the daily routine.

For linguistic description of the patient-related orientation of arbitrarily-aligned exposures, letters or letter combinations are therefore generally used in radiology
15 as what are known as “orientation markers”. Typical letters for use as orientation markers are:

A for “Anterior” (front)
P for “Posterior” (back)
20 L for “Left” (left)
R for “Right” (right)
H for “Head” (head-side)
F for “Feet” (foot-side)

25 These direction specifications are also indicated in Figure 1 for clarification. Letter combinations such as, for example, “LP” for a combination made up of Left and Posterior can also be formed from these as further orientation markers. Via these orientation markers, the position of the direction vectors spanning the acquisition plane is described relative to the primary coordinate system of the
30 patient in the form of linguistic designations easily understandable for the health

professional. The orientation markers are thereby typically graphically represented on the edge of the exposure, as in a geographical map.

5 All such patient-related information regarding the position and orientation of the slice image exposures such as, for example, the specification of orientation markers in the primary coordinate system of the patient must refer to a reference coordinate system which is oriented on the body of the patient. In contrast to this, in the data acquisition the coordinates of the individual volume elements from which the image information are acquired are determined in a fixed coordinate
10 system with regard to the tomograph. The position of the patient must therefore remain known relative to the MR apparatus during the image data acquisition. Only under this condition can the desired patient-related information regarding the position and orientation of the slice image exposures in an magnetic resonance tomographic examination be definitely determined.

15 In the MR apparatuses typical today, the patient is inserted into the apparatus via a horizontally-movable patient bed and the position of the patient is described by the operator of the MR apparatus. Differentiation is thereby normally made between a head and foot position as well as between a stomach, back, left-side and right-side
20 position. The operator typically has to select between a plurality of possible patient positions from a selection list. A detailed description of the position of the patient, in particular a description of the arm position (for example whether the arm lies on the body or over the head) does not occur. After the specification of the patient position, the control software of the MR apparatus assumes that the
25 patient is located in the described position in the normal position and consequently determines the primary coordinate system of the patient on the basis of this normal position. Given the production of an exposure, its orientation is then documented relative to this primary coordinate system. This means that, given the determination of the orientation markers that are ultimately graphically shown on
30 the edge of the exposure for specification of the position of the exposure for the

examining doctor, it is assumed that the patient is located in the normal position in the specific position.

5 An incorrect description of the patient position by the operator can thus single-handedly lead to incorrect orientation markers in the procedure typical today. The same problem occurs when the bearing of the patient does not corresponding to the normal position. Moreover, it can thereby also occur that correct orientation markers result again from an incorrect description of the patient position in combination with a bearing of the patient deviating from the normal position.

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The quality demands for information regarding the position and orientation of the exposures can understandably hardly be set too high. For example, an incorrect direction designation in a cranial exposure with a diagnosed brain tumor has fatal consequences for the operation planning. The operative entry could then be
15 incorrectly selected. A correct determination of orientation markers is in particular very important in extremity exposures (arms and legs) and given symmetrical anatomy (for example in the cranium). However, the situation is particularly error-prone in examinations of the upper extremities. These can be positioned next to the body along the longitudinal body axis or be positioned over the head in the
20 same direction, whereby an additional rotation movement of the hands relative to the elbow joint is still possible. This leads to a plurality of positioning possibilities that cannot practically be covered by all-inclusive position specifications. On the other hand, for many examinations an individual patient positioning deviating from the positioning variants allowed by the system is absolutely reasonable or,
25 respectively, even essential in some cases. This clarifies the problem of an objective and standardized description of the patient position, which is an essential requirement for the correct determination of orientation markers.

30 In addition to the correct orientation determination, a reliable designation of the examination region is also important. For example, it must thus be ensured that it

is unambiguously certain whether, for example, an examined extremity is the left or right extremity.

The determination of the examination region is normally coupled with the selection
5 of a measurement program. In the MR apparatuses today, an abundance of
measurement programs are supplied by the manufacturer that are normally
hierarchically classified. An important sorting criterion is the associability with an
anatomical region since some measurement parameters are optimized for the
corresponding anatomical region (i.e. a specific examination region). For example,
10 measurement programs for knee examinations are centralized in a measurement
program folder with the designation "knee". The suitable measurement protocols
can then be sorted even further dependent on the diagnostic question (such as, for
example, meniscus lesion, cartilage damage, ...). The information about the
associated examination region is normally linked with the selection of a
15 measurement program, whereby this information enters into the linguistic
designation of the produced exposures. These exposures are typically
hierarchically organized in a databank, whereby the sorting criterion for the
uppermost level is normally the patient name. The information about the
examination region, which results from the name of the measurement program, is
20 used as a sorting criterion in a lower level. However, given some questions no
unambiguous designation of the examination region is possible with this
procedure. This is, for example, the case given the use of one and the same
measurement program both for the left knee and for the right knee. For
unambiguous designation of the examination region, the operator can still input a
25 comment in the control software (for example left knee) which is then graphically
shown on the measured exposure.

This typical procedure for determination of examination regions also contains a
plurality of error sources. The manufacturers of MR apparatuses generally give the
30 operator freedom over the sorting and linguistic designation of measurement
programs. No logical linguistic designations of measurement programs must

thereby be used. Illogical linguistic designations of examination regions can thus also occur. The use of comments is likewise a possible error source. For example, the operator only has to confuse the left knee with the right knee and incorrect image comments are already shown in all measured exposures. The combination
5 with an incorrect specification of the patient position would aggravate this situation even further. The correct patient-related reconstruction of the position and orientation of a measured exposure is the possibly no longer possible.

An exact knowledge of the patient position is therefore likewise of decisive
10 importance for monitoring of an examination region established by the operator. If the patient position is known in detail, this information can be checked from the relative positions of the exposures with regard to the patient.

An objectified determination of the patient position is possible in various ways and
15 is of importance not only in MR diagnostics. Patients should in particular be reproducibly positioned and their position monitored in therapeutic radiation therapy. In the meanwhile [sic], optical methods are possible in addition to the positioning by means of mechanical devices such as a displacement table and stereotactic fixing. Examples for this are described in US 5,080,100, US 6,279,579
20 and US 5,823,192. They are based on optical measurement systems for three-dimensional surface acquisition or use tracking systems for three-dimensional coordinate detection such as, for example, in the method proposed in US 6,138,302. A transition to the situation in MR examinations is, however, problematic in many aspects. For description of the patient position, the body
25 surface of the patient would have to be measured, which requires an almost completely disrobed patient. This cannot be required in the daily routine. An optical measurement of the patient in the MR apparatus is additionally made significantly more difficult due to the typical tube-shaped construction.

30 Another possibility of the documentation of the patient position is the reconstruction of the body surface of the patient from a volume data set. The

reconstruction of surfaces (among which the body surface also counts) from volume data sets is described in US 4,821,213 and US 4,719,585. The measurement of volume data sets of the entire patient for detection of the patient position is much too complicated due to the high number of exposures to be
5 produced.

It is therefore an object of the present invention to specify a method that enables a standardized and objective description of the patient-related position and orientation of exposures in a magnetic resonance tomographic examination.
10 Furthermore, a corresponding control device for operation of a magnetic resonance tomography apparatus should be achieved.

This object is achieved via a method according to claim 1 or, respectively, via a control device according to claim 14.

15 According to the invention, a method for determination of patient-related information regarding the position and orientation of slice image exposures in magnetic resonance tomographic examinations is proposed in which initial MR overview exposures (magnetic resonance overview exposures) of the body of the
20 patient are initially produced. Using these initial MR overview exposures, a predetermined, parameterized anatomical body model (i.e. an anatomical body model) with specific variable model parameters is then individualized. The determination of the patient-related information about the position and orientation of the subsequent (diagnostic) slice image exposures then ensues on the basis of
25 the relative position of the slice image exposures with regard to the individualized body model. In the individualization, via variation of the model parameters the body model is adapted to specific structures determined from the initial MR overview exposures, which specific structures advantageously represent the body surface of the patient. The individualization process thereby corresponds to a
30 mathematical optimization problem. Those values of the variable model parameters are determined that minimize a deviation measure of the model relative

to the structures from the overview exposures. This means that an optimally good adaptation of the body model to the entire body of the patient in the actually-present current position essentially ensues.

- 5 Via the individualization process, information can be transferred from the body model to subsequent diagnostic exposures. A linking of information with the body model located in the normal position (also called "norm model" in the following) is in particular possible, which information also describes the orientation of each part of the norm model in addition to the body region. After the individualization
- 10 process, both information regarding the position of the exposure in text form and information regarding the orientation of the exposure in the form of orientation markers can be determined from the relative position of an exposure with regard to the parts of the individualized body model located in the immediate neighborhood. This means, for example, that all image pixels or volume elements that exhibit less
- 15 than a predetermined maximal spatial interval from a region that is defined by a specific body part of the individualized model can be counted in a later MR exposure as components of the appertaining body part of the patient.

- The advantages achieved with the invention in particular exist in that patient-
- 20 related information regarding the position and orientation of slice image exposures in magnetic resonance tomographic examinations can be determined objectively and in a standardized manner. This in particular concerns the automatic generation of orientation markers and text specifications regarding the examination region. An independence is thereby achieved in the determination of the described
- 25 information by the operator of the MR apparatus, which directly leads to a quality increase of a subsequent medical diagnosis.

- In addition to a control interface for activation of the magnetic resonance tomography apparatus for measurement of a number of slice image exposures
- 30 corresponding to scan parameters predetermined by the control device and an image data interface for reception of image data acquired by means of the magnetic

resonance tomography apparatus, for implementation of the inventive method a control device for operation of a magnetic resonance tomography apparatus must comprise an overview image determination unit in order to activate the magnetic resonance tomography apparatus for measurement of a number of initial MR
5 overview exposures of the body of the patient. Moreover, the control device requires: a storage device with an anatomically parameterized body model whose geometry is variable via a modification of specific parameters; an individualization unit in order to individualize the body model using the measured initial MR overview exposures; and a localization unit which respectively determines the
10 relative position of the appertaining slice image exposures with regard to the individualized body model for determination of patient-related information about a position and orientation of subsequently-created slice image exposures.

The individualization unit and the localization unit can thereby particularly
15 preferably be realized in the form of software on a programmable processor of a control device of a magnetic resonance tomography apparatus. Moreover, the storage does not necessary have to be an integrated part of the control device; rather, it is sufficient when the control device can access an external storage device.

20 The dependent claims respectively contain particularly advantageous developments and embodiments of the invention, whereby the inventive control device can also be developed corresponding to the method claims.

25 An advantageous embodiment of the invention is characterized in that the initial MR overview exposures are produced in a standardized arrangement. Fast MR sequences can thereby be used that are characterized by an acquisition time per overview acquisition in the second range. The advantage achieved with this embodiment of the invention is that a uniform examination protocol can be used
30 for acquisition of the overview exposures for each patient. A manual adaptation to the individual patient geometry is not necessary. Moreover, the individualization

algorithm is started with a uniform data basis, which increases the stability of the results.

5 Cross-section exposures (i.e. exposures oriented transverse to the longitudinal body axis of the patient) are particularly preferably produced as initial MR overview exposures. Cross-section exposures lend themselves to the individualization of a whole-body model since a complete imaging of the body surface is possible in each cross-section exposure. This is generally not the case in exposures along the longitudinal body axis. A complete reconstruction of the body surface of the
10 patient is thus possible in each cross-section exposure given a production of cross-section exposures as initial MR overview exposures. This information increases the stability of the individualization algorithm.

In order to achieve a sufficient model individualization, at least three cross-
15 sections with an interval of approximately 50 cm (given an adult) should be produced as initial MR overview exposures. However, the separation of two adjacent cross-section exposures advantageously lies below 50 cm, particularly preferably even below 15 cm. The more overview exposures that should be produced, the more easily that the individualization problem can be solved due to
20 the improved data basis. In practice a compromise must therefore be found between stability and time expenditure. It has turned out that a slice separation of approximately 10 cm in the acquisition of the entire patient position represents a good compromise between precision and speed. Moreover, equidistant slice separations do not necessarily have to be selected over the entire body. For
25 example, an acquisition of the hand geometry with the finger positions requires a higher spatial density of overview exposures than the acquisition of the trunk geometry. For example, insofar as a hand should be examined in detail, a local slice interval of two centimeters can be reasonable there. For example, a slice interval of five centimeters is normally sufficient in a foot examination.

It is in particular also possible to initially produce first initial overview images in a rougher grid. Insofar as the quality of the individualization (which is characterized by the deviation degree to be determined anyway in the individualization) is not sufficient, further overview exposures can be produced at a suitable location. In a particularly advantageous embodiment of the invention, the positions and orientations of, if applicable, additional MR overview exposures to be produced are automatically determined via the individualization algorithm given insufficient quality of the individualization. A quantification of the quality thereby occurs via a calculation of a deviation degree of the body model relative to structures from the overview exposures. This means that the positions and orientations of the additional overview exposures can be determined from the individual algorithm from the analysis of the model deviation relative to structures in the individual overview exposures and the respectively-mapped body region. The advantage achieved with this embodiment of the invention is in particular that, given insufficient quality of the individualization, additional overview exposures are produced via an automatically-running method until a sufficient quality of the individualization is achieved.

A further advantageous embodiment of the invention is characterized in that the model parameters adjustable in an individualization comprise at least one translation parameter, one rotation parameter and one scaling parameter of the entire body model as well as further parameters that describe the spatial position and shape of predetermined important body parts such as, for example, the extremities. The number of the parameters for description of the human anatomy primarily depends on the required precision of the modeling. In order to obtain information about the position and orientation of exposures in MR examinations, a precise modeling of anatomical structures internal to the body is of subordinate importance. Rather, a modeling of the movement possibilities of significant body parts and their surface is relevant. A sufficient but not too-detailed modeling of the human anatomy is achieved via the parameterization of the position and shape of the significant body parts.

A relatively simple (however in many situations sufficient) model can thereby be described, for example, by the following parameters:

- 5 body size, arm length, leg length, angle specifications for description of shoulder, elbow, hand, hip, knee and ankle joint, circumference of chest and abdomen.

The following parameters can, for example, be added given a more complex model:

- 10 shoulder height, length of upper, lower arm and hand or, respectively, upper, lower leg and foot, angle specifications for description of the head position and of the spinal column divided up into neck, chest and lumbar region as well as the fingers and toes, circumference of head, neck, shoulder, upper arm, lower arm, hand, hips,
15 upper leg, lower leg and foot.

- In a further advantageous embodiment of the invention, a linguistic designation of the patient position is determined from the parameter values of the individualized model (for example head or feet forward; back, stomach, left side, right side
20 position). The three fundamental model parameters for description of the rotations around the three primary axes are hereby of particularly importance. From these parameters and the further model parameters, conclusions can be drawn about the linguistic designation of the patient position in the MR apparatus. The difference between the position with the head forward and the position with the feet forward
25 exists in a rotation angle different by 180° around the sagittal axis. The back, stomach, left-side and right-side position is primarily differentiated via the rotation angle around the longitudinal axis. The advantage achieved with this embodiment of the invention is in particular that a linguistic designation of the patient position can be determined objectively and in a standardized manner via the parameter
30 values of the individualized model.

A description of the patient position that is input by the operator can thereby particularly preferably be monitored with the aid of the parameter values of the individualized model. Insofar as the linguistic designations of the patient position that are possible via the individualization algorithm coincide with the selection
5 possibilities of the patient position description by the operator, the description of the patient position that is input by the operator can be automatically monitored. A quality increase of the examination is achieved via such a monitoring of the patient position description via the individualization algorithm.

10 In a particularly preferred embodiment of the invention, the patient-related information about the position and orientation of slice image exposures is encoded in linguistic and/or graphical form and represented with the individualized model. Patient-related information (for example by means of text specifications and orientation markers) about the position and orientation of slice images are normally
15 represented in the individual exposures. However, for better clarity the individual exposures can also be represented three-dimensionally in their position and orientation with the individualized body model. The advantage achieved with this embodiment of the invention is in particular that, in addition to the patient position, the position of the exposures with regard to the patient can also be graphically
20 represented in a simple and detailed manner via this method.

The body weight of the patient can advantageously be calculated with the aid of the individualized body model. A body weight input by the operator or, respectively, already present in a patient data file can in particular be monitored.
25 The body weight of the patient is in particular important for calculation of the specific absorption rate (SAR). The volume (and from this the body weight of the patient) can be estimated from the individualized body model. An additional quality increase of the examination is consequently achieved via the monitoring of the body weight via the individualization algorithm. In particular the SAR limit
30 values are reliably maintained.

In a further advantageous embodiment of the invention, a positioning of the patient in the MR apparatus for examination of a desired region is implemented with the aid of the individualized model. The method for determination of information regarding the position of exposures is reversed given this question. An
5 examination region is then provided and a suitable initial position for subsequent exposures is sought. For this, those parts of the individualized model with which the desired region is linked are determined for the desired examination region. A table displacement which brings the examination region into the magnetic field center is calculated from the spatial position of these parts. This procedure enables
10 an automatic positioning of the patient dependent on the desired examination region. A time-consuming manual positioning of the region to be examined, which is normally implemented with laser light beam localizers, can then be omitted.

A model individualized in a first MR examination is particularly preferably stored
15 and a positioning of the patient in a further MR examination is implemented with the aid of this individualized body model. In this manner it can, for example, be ensured that the patient optimally assumes exactly the same position in a later MR progressive examination as in the first MR examination. The adoption of the same patient position is of decisive importance given a progressive examination. In
20 particular the joint positions and the shape of the soft parts are dependent on the positioning. Not just a qualitative comparison is possible via the comparison of a model individualized in the subsequent progressive examination with the stored individualized model. A degree of deviation of both models can also be calculated, and this can be used for adoption of the same patient position. The sum of the
25 deviation squares of corresponding model triangles lends itself as a measure of deviation of both different individualized models. This definition is unambiguous since the two form-variable models differ only by the spatial positions of the model triangles, whereby the triangle count as well as the neighborhood relationships of the triangles remain unaltered. A quality increase of the examination is achieved
30 via the manageable adoption of an optimally identical patient position in an MR progressive examination.

A signal is advantageously emitted given an incorrect process and/or given the end of one or all method steps. When a notification of the operator ensues via a signal given automatically executing method steps, the operator can also apply himself to
5 other tasks. This increases the workflow in the examination.

The invention is explained in detail in the following under indication of attached Figures using an exemplary embodiment. Shown are:

10 Figure 1 a schematic representation of the primary coordinate system and the primary planes of the body of a patient,

Figure 2 a flow diagram regarding clarification of a possible workflow of the inventive method,
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Figure 3a a schematic representation of a patient in the normal position on a patient bed, lying on his back,

Figure 3b a schematic representation of a patient in a position deviating from
20 the normal position, lying on his back,

Figure 4 a schematic representation of a magnetic resonance tomograph with an exemplary embodiment of an inventive control device.

25 As already explained above, Figure 1 illustrates the primary coordinate system of the body of a patient in the normal position.

A possible workflow of the inventive method as shown in Figure 2 comprises the following steps after the positioning of the patient:

30

a.) Production of a plurality of initial MR overview exposures of the patient.

- b.) Individualization of a parameterized anatomical body model on the basis of the produced initial MR overview exposures.
 - c.) Given insufficient quality of the individualization, additional MR overview exposures are produced and the individualization method is re-implemented.
 - d.) Graphical representation of the individualized model for method monitoring.
 - e.) The method is interrupted by the operator given insufficient description of the patient position by the individualized model.
 - f.) Production of diagnostic MR exposures.
 - g.) Determination of information regarding the position and orientation of MR exposures from the relative position with regard to the individualized model.
- For model individualization, cross-section exposures in standardized arrangement thereby lend themselves as initial overview exposures since a cohesive reconstruction of the body surface is then possible in the individual cross-section exposures. A single threshold method can be used for this, whereby the jump in the signal intensity from air to skin defines the body surface. Due to the (in the meanwhile [sic]) large geometric measurement regions of the MR apparatuses, it can normally be assumed that complete cross-sections of the patient are acquired in the measurement. This leads to a contiguous reconstruction of the body surface in the individual cross-section exposures that is mathematically expressed in the description of the body surface via closed continuous lines. These form the target structures in the individualization.

Schematically shown in Figures 3a and 3b is, respectively, a patient PT lying on his back in the normal position (Figure 3a) on a patient positioning table 3 and deviating from the normal position in a position (Figure 3b), likewise lying on his back, however with the right hand over the head. Moreover, the exposure planes AE are shown in which the initial cross-section overview exposures are produced.

The separation of the exposure planes here is approximately 10 cm. These Figures illustrate very well that, given corresponding separation of the cross-section exposures relative to one another, a positioning of an extremity of the patient PT that does not correspond to the normal position is acquired well, and this posture
5 correspondingly, ultimately, correctly reproduces the individualized body model.

In addition to the target structures, a suitable body model is still required for the individualization process, whereby the variable parameters of said body model are not unambiguously determined. Only the underlying parameters for the
10 elementary transformations such as the translation, the rotation and the scaling of the body model are clear. In contrast to this, the type and number of the parameters describing the model geometry primary depend on the usage purpose.

In order to acquire information about the position and orientation of exposures in
15 MR examinations, a modeling of the movement possibilities of significant body parts and their surface is primarily relevant. A design of the body model from a plurality of contiguous volume elements thereby lends itself, whereby their dimensions lie in the centimeter range and the concrete model geometry is determined by a set of parameter values. Suitable methods are described in the
20 article "Simulating facial surgery using finite element models" by Koch et al. (Proceedings of the SIGGRAPH 1996 conference, p. 421 – 428) for a finite element model or in the article "A 3D anatomical atlas based on a volume modell" by Höhne et al. (IEEE Computer Graphics Applications, 1992, volume 12, nr. 4, p. 72-78) for a voxel model.

25 Very simple body models can, for example, be described via only one pair of parameters such as, for example, body size, arm length, leg length, chest circumference, abdomen circumference as well as parameters for description of the arm and leg position.

30

- Complex body models with a large parameter count are juxtaposed with this. Not only the body surface but also sometimes the skeleton system is [sic] thereby modeled. The geometry of the human back is thus, for example, described via the following parameters: Distantia cristarum, Distantia spinarum, Diameter spinarum posterior, Diameter transversa of the pelvic width, Diameter transversa of the pelvic strait, Diameter transversa of the pelvic outlet, Diameter sagittalis of the pelvic width, Diameter sagittalis pelvic strait, Diameter sagittalis pelvic outlet, Conjugata anatomica, Conjugata diagonalis, Conjugata vera.
- 10 In order to obtain information about the position and orientation of exposures in MR examinations, however, such a precise modeling normally not necessary. Depending on the desired precision, a modeling of the significant body parts is sufficient. The position of the body parts is thereby primarily described by the degree of freedom of the anatomical joints. For example, in general three
- 15 parameters (namely dilation and deflection, abduction and adduction, inner rotation and outer rotation are sufficient for description of the hip joint (which is a ball joint). The shape of a femur can, for example, be parameterized via two respective diameters arranged at the start, in the middle and at the end of the femur and situated perpendicular to one another, which diameters represent the primary axes
- 20 of the (in good approximation) oval femur. One can also similarly proceed with the other body parts such as head, neck, chest, abdomen, back, shoulder girdle, upper arm, lower arm, hand, lower leg, foot. At least the movement possibilities of the large joints of the human body should thereby advantageously be parameterized. The relevant joints are thereby: upper and lower ankle, knee joint,
- 25 hip joint, shoulder joint, elbow joint, wrist.

- The spinal column adopts an exceptional position. It comprises a plurality of joints between the individual vertebrae and the movement possibilities can be parameterized in detail only with effort. However, a sub-division of the spinal
- 30 column into the neck, chest and lumbar spinal column with simplified movement possibilities is reasonable for the description of the patient position.

In examinations of the finger that occur quite seldom, another additional parameterization of the movement possibilities of the finger joint is reasonable.

- 5 The value range of the individual parameters is advantageously limited. The limitation thereby ensues such that only such parameter value combinations are allowed that describe an anatomically-possible position of the patient. The parameter values belonging to the normal position of the model (norm model) are also designated as normal parameter values.

10

- The individualization algorithm can then be started with the described target structures in the individual overview exposures and the body model. The goal is thereby the determination of a set of parameter values that minimize the deviation of the body model relative to the target structures on the overview exposures. The
15 individualized body model with the individualized parameter value set is obtained as a result.

- The deviation of the body model relative to the target structures is described by a deviation function, whereby the arguments of the deviation function are the model
20 parameter values. Mathematically, a nonlinear optimization problem exists, namely the question of the minimum of the deviation function. Each allowed parameter value combination leads to a body model with specific geometry, which body model is made up of volume elements. One possible deviation function can then be defined via the deviation values of the surface elements of the body model.
25 The calculation of the deviation as a weighted sum of the squares of the deviation values from the individual surface elements thereby volunteers itself. The weighting factor of a surface element is thereby the ratio of the areal content of the surface element to the average value of the areal contents of all surface elements. This way of deviation calculation via the use of the model surface is reasonable
30 since the target structures are parts of the body surface of the patient.

- The minimal geometric separation from the target structures is defined as a deviation value of a surface element, insofar as the surface element geometrically intersects an overview exposure. Otherwise, the deviation value is not defined. This is reasonable since, for example, no information about the separation relative to the body surface of the patient exists anyway for a surface element situated in the middle between two overview exposures. A different number of surface elements thus enter into the deviation calculation depending on the position of the body model. In order to nevertheless be able to calculate comparable deviations from these values for different parameters, a deviation normalization via the areal content of all surface elements incorporated into the calculation is reasonable. The optimal parameter set for minimization of the deviation can then be determined via conventional search path or raster methods. Suitable methods are, for example, described in "Numerische Mathematik", R. Schaback, Springer Verlag, 1992.
- 15 The quality of the individualization is quantified by the value of the calculated deviation. If this lies below a predetermined limit value, the individualization has been successfully implemented. When it does not, further overview exposures are then produced at points with the largest deviation values from the surface elements to increase the adaptation quality. The body surface of the patient is thus exactly dimensioned at the critical regions determined by the individualization algorithm. This procedure is iteratively run through until a sufficiently exact description of the patient position is achieved by the body model or it is interrupted after a certain iteration number given insufficient convergence behavior.
- 25 The three-dimensional graphical representation of the individualized body model enables the operator a control of the individualization via the comparison with the actual patient positioning. Upon occurrence of relevant deviations, the operator can abort the method and continue working conventionally.
- 30 Given successful individualization, patient-related information regarding the position and orientation of the exposures can be determined from the relative

position of the subsequent diagnostic exposures with regard to the individualized body model. For this, information is linked with each volume element of the norm model before the individualization. This information sometimes describes the body region and orientation of each volume element. For example, the information “right knee” in text form is linked with all volume elements of the norm model that form the right knee. Information in text form regarding the position of the exposure can then be acquired after the individualization process from the relative position of an exposure with regard to the associated volume elements of the individualized body model. If, for example, the exposure intersects only volume elements with the linked information “right knee”, then “right knee” can also be specified as an examination region of the exposure (i.e. as position information regarding the exposure). The information regarding the body region would thus transfer from the individualized body model to the exposure and there designate the examination region.

It behaves the same with orientation markers. The orientation of a volume element is described by a local coordinate system, whereby in a normal position all local coordinate systems coincide with the primary coordinate system. After the individualization, these then normally no longer coincide. If, for example, the patient is positioned with the arms over the head, after the individualization the local coordinate systems in the volume elements of the hand describe the local orientation axes and differ from the local orientation axes at the torso. If an exposure then images the hand of the patient, information regarding the orientation of the exposure can then be acquired from the relative position of the exposure with regard to the corresponding volume elements of the hand. The orientation markers of the exposure then locally refer to the hand and no longer refer to a uniform coordinate system for the entire patient.

A linguistic designation of the patient position can also be acquired as an ancillary product from the parameter values of the individualized body model (for example head or feet forward, back, abdomen, left side, right side position), whereby the

three parameters for description of the rotation around the three primary axes have a prominent importance. For example, the back, abdomen, left-side and right-side positions primarily differ by the rotation angle around the longitudinal axis. In contrast to this, the positioning of the arms is primarily described by the

5 parameters for description of the shoulder as well as elbow joints. A linguistic designation of the patient position can be associated with each set of parameter values. In practice, a linguistic designation of the patient position in tabular form can be defined for an endless number of parameter value sets. For an arbitrary parameter value set, the parameter value set corresponding best is then determined

10 from the table with associated linguistic designation of the patient position and displayed to the operator in text form. The patient position description in text form also enables a simple monitoring of the description of the patient position selected by the operator, insofar as in both cases the same pool of linguistic designations was used.

15

Patient-related information about the position and orientation of exposures are normally graphically represented in the exposures, for example via text specifications and orientation markers. In addition to this two-dimensional representation form, a three-dimensional visualization of the individual exposures

20 with the individualized body model volunteers itself. Various 3D representation techniques can be used for this. For example, hardware-accelerated methods on a triangle basis (SSD method, Surface Shaded Display) as it is described in the “OpenGL Programming Guide”, Woo et al., Addison Wesley publishing, 3rd edition, 1999 lend themselves to real-time visualizations. This visualization

25 technique enables an interactive observation of the scenery in real time and nevertheless possess a sufficient representation quality. A simple as well as intuitive representation of the significant information is achieved via simultaneous visualization of the triangulated model surface with the produced exposures in their three-dimensional position and orientation, whereby the text specifications and

30 orientation markers can also be mapped as well.

Further information can also be extracted from the individualized body model in addition to the information regarding the position and orientation of exposures.

The estimation of the body weight of the patient is thereby quite simple. A density is associated with each volume element of the body model before the

5 individualization. After the individualization, the weight of said volume element is calculated from this information and the volume of the volume element. The sum of the weights of the individual volume elements then yields the estimated value of the patient weight.

10 Other information enables an automatic positioning of the patient for examination of a desired body region in the MR apparatus. This method uses the information about the associated body region, which information is linked with each volume element. For this, those volume elements of the individualized body model with which the linguistic designation of the region is linked are determined for the
15 desired examination region. The geometric center of these volume elements defines the center of the examination region and is brought into the magnetic field center via a then-defined table displacement. For example, with one patient it is desired to examine the right knee. After the individualization, the positions of volume elements with the linked information "right knee" are known. The center
20 point of these volume elements then defines the position with regard to the examination of the knee. The table displacement results as a difference between magnetic field center and the calculated center point.

A further application possibility of individualized body models exists in the
25 adoption of the same patient position in progressive examinations. For this, the model parameter values of the reference examination are stored and re-imported in a progressive examination. These parameter values then define the reference model. For adoption of the same patient position, the individualized body model of the progressive examination (progressive model) is compared with the reference
30 model. The goal is a deviation minimization of the two body models. For this, a deviation value is associated with each surface element of the progressive model,

whereby this deviation value is defined as a geometric distance from the corresponding surface element of the reference model. The deviation is defined as a sum of the squares of the deviation values. The patient position is varied in the progressive examination until the respectively newly-determined progressive
5 model shows a sufficient correlation with the reference model. A simultaneous three-dimensional representation of both models with a color coding of the deviation values is helpful for this.

An exemplary embodiment of an inventive magnetic resonance tomography
10 apparatus 1 with an associated inventive control device 5 is shown roughly schematized in Figure 4.

In the shown exemplary embodiment, the control device 5 is housed in a separate apparatus. It is hereby a computer with a programmable processor 10 on which is
15 stored the control software for activation of the magnetic resonance tomography apparatus 1. The control device 5 transmits control commands SB to the magnetic resonance tomography apparatus 1 via a control interface 8 so that the desired measurement is implemented by this magnetic resonance tomography apparatus 1. The raw image data BD acquired by means of the magnetic resonance tomography
20 apparatus 1 are transferred via the image data interface 9 and then further-processed within the control device 5 in a typical manner.

In order to be able to operate the control device 5, it is connected to a console 4 which, as, a user interface, comprises a screen, a keyboard and a pointer device
25 (for example a mouse). However, it is alternatively also possible that, instead of ensuing via the console 4 directly connected to the control device 5, the operation ensues, for example, via a workstation (not shown) which is connected to a bus 7 with which the control device 5 is connected. However, the console 4 can also be an integrative component of the control device 5. The control device 5 can
30 likewise also be an integrative component of the magnetic resonance tomography apparatus 1, such that all components are comprised in one apparatus.

The magnetic resonance tomography apparatus 1 is here a conventional magnetic resonance tomography apparatus with typical radio-frequency, gradient and basic magnetic field coils (not shown). The patient PT is positioned in the magnetic
5 resonance tomography apparatus 1 on a patient positioning table 3 within a measurement chamber 2 around which the coils are arranged. Local coils can additionally be used that are positioned directly on the patient PT. The features and the functionality of a magnetic resonance tomography apparatus 1 are known to the average man skilled in the art and do not need to be explained further here.

10

The core part of the control device 5 is a processor 10 on which various components are implemented in the form of software so that the control device 5 functions in the inventive manner. These components are schematically represented in Figure 4 as blocks within the processor 10. In addition to the shown
15 components, the control device 5 naturally comprises all further typical software or, respectively, hardware components in order to be able to control a magnetic resonance tomography apparatus in a typical manner and acquire and (pre-)process image data. However, for better clarity these typical components are not shown in the Figure and are also not explained in detail in the following insofar as they were
20 not specially modified for the inventive function.

Such a component is an image determination unit 12. This image determination unit 12 converts various measurement protocols or, respectively, scan parameters thereby predetermined (with which measurement protocols or, respectively, scan
25 parameters it is signaled to the magnetic resonance tomography apparatus 1 in which position or, respectively, orientation image data should be determined) into control commands SB. These are then transferred to the magnetic resonance tomography apparatus 1 via the control interface 8 so that there the matching measurement sequences are conducted in the correct order in order to generate the
30 desired slice images. For realization of the invention, the image determination unit 12 comprises an overview image determination unit 13 (here as a subroutine)

which ensures that the magnetic resonance tomography apparatus is controlled such that a number of initial MR overview exposures (such as, for example, shown in Figures 3a and 3b) are measured.

5 The MR overview exposures generated in these overview scans are then (like all remaining image data BD) transferred from the control device 5 via the image data interface 9 and further processed there [sic]. For example, in a reconstruction unit 11 the desired images are initially reconstructed from the determined raw image data BD. The MR overview exposures UA so determined are then transferred to
10 an individualization unit 14.

This individualization unit 14 contains a structure detection unit 15 as a subroutine which determines the necessary structures (here the boundary surfaces between the body of the patient PT and the environment, i.e. the surface structure of the body of
15 the patient PT) from the overview exposures UA. The individualization unit 14 additionally contains an adaptation unit 16 which adapts a norm model NM to the target structure via adjustment of specific, variable parameters of the norm model NM (i.e. a body model in normal position) as this was already described in detail above. Such a norm model NM is stored in a storage 6 of the control device 5.

20 The finished, individualized body model IM can then again be stored in the storage 6. All data that describe the complete, individualized body model IM do not necessarily thereby have to be stored. In principle it is sufficient when a set of parameter values is stored with which the individualized body model IM can be
25 generated from the norm model NM. The data set of the individualized body model IM is moreover transferred to a localization unit 17. The relative position of the subsequent (diagnostic) slice image exposures with regard to the individualized body model IM can then respectively be determined with the aid of this localization unit 17, and the patient-related information about a position and
30 orientation of the subsequently generated slice image exposures can thus be determined in the inventive manner.

Moreover, the individualization unit 14 has the possibility to output a signal to the overview images determination unit 12 in order to ensure that a larger number of overview images situated more closely to one another are additionally produced in
5 specific spatial regions in order to improve the quality of the individualization.

At this point, it is once again expressly noted that the processes and system architectures shown in the Figures are only exemplary embodiments that can be modified in detail without further measures by an average man skilled in the art.
10 In particular it is possible that most varied components of the control device 5 are realized not on a processor but rather on various processors networked among one another. Naturally, it is likewise also possible that the various components are realized on different computers networked with one another. For example,
15 particularly calculation-intensive processes such as the individualization of the model can thus be sourced out to suitable computers via the bus 7, which suitable computers then deliver back only the end result.

Moreover, it lends itself to retrofit existing control devices or, respectively, magnetic resonance tomography apparatuses with the inventive components in
20 order to also use this device [sic] according to the inventive method described in the preceding. In many cases, an update of the control software with suitable control software modules is sufficient.